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Multiple Scatters in Single Site Gamma Backgrounds

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Multiple Scatters in Single Site Gamma Backgrounds

I. AIM OF THIS STUDY

nEXO aims to reduce its gamma backgrounds by taking advantage of the fact that a large number of gammas that would otherwise be backgrounds will undergo multiple compton scattering in the TPC and produce spatially distinct signals. These multi-sited (MS) events can be excluded from the $0\nu\beta\beta$ search.

Roughly 90% of gamma backgrounds are identifiably MS. The remaining single-sited (SS) backgrounds include gammas whose only interaction in the TPC is to undergo photoelectric effect on the LXe, producing a single electron. Also included in the SS category are:

- gammas which truly have multiple interaction sites but only one interaction above the detection threshold

- gammas with mutliple interaction sites that are separated by more than our nominal resolution but are not separately resolved due to measurement fluctuations in our particular event

- gammas with multiple interaction sites inside our nominal resolution

The aim of this study is to quantify the population of the last category. Doing so furthers our understanding of the limits of gamma discrimination techniques. Improvements in our ability to resolve separate sites can only exclude backgrounds that actually have separate sites. Similarly, techniques that observe directional behavior in the recoil electrons will have a difficult time telling a double beta decay apart from a gamma that scatters twice.

II. DEFINITION OF BACKGROUNDS

Backgrounds were simulated by generating Tl-208 decays in the SiPM cable layer. This creates $2615\,\mathrm{MeV}$ gammas from a location outside the TPC. As the purpose of this study is to study the behavior of backgrounds, not to count the number of backgrounds, I don't believe it is important to simulate gammas from other locations.

For the purposes of this study, a gamma is considered a background if:

1. There is only one cluster of energy depositions. Clustering is performed by sequentially comparing each energy deposition to the existing clusters. If the deposition is within $3\,\mathrm{mm}$ of an existing cluster, its energy is added to the cluster and the cluster's position is moved to the energy-weighted average of its old position and the position of the newly-added deposition. If the deposition is not within $3\,\mathrm{mm}$ of any existing cluster, it forms a new cluster. This clustering algorithm has the unfortunate property of being slightly sensitive to the order depositions are recorded in the MC, but I believe any effects stemming from this property to be minor.

2. The total event energy is greater than the $0\nu\beta\beta$ Q-value -1%, $2.43342\,\mathrm{MeV}$. Excluding the upper edge of the $0\nu\beta\beta$ energy window would increase simulation requirements without, I believe, meaningfully changing the results.

3. The single cluster is within the fiducial volume, defined as radius $< 559\,\mathrm{mm}$ and $-604\,\mathrm{mm} < z_C < 618\,\mathrm{mm}$, where z_C is measured from the center of the TPC (as opposed to the MC coordinate system, which places the TPC center's z-position at $-403\,\mathrm{mm}$.

III. COUNTING GAMMA INTERACTIONS

A gamma interaction in liquid xenon will produce a recoil electron. Gamma interactions can be counted by counting the number of electron secondary particles produced from gamma parents. This is done during nEXO_MC's PostUserTrackingAction, a time when the secondary production of each parent particle can be analyzed.

The conditions to increment the count of gamma interactions are:

1. The parent particle must be a gamma.

2. The secondary particle must be an electron.

3. The interaction must be in liquid xenon.

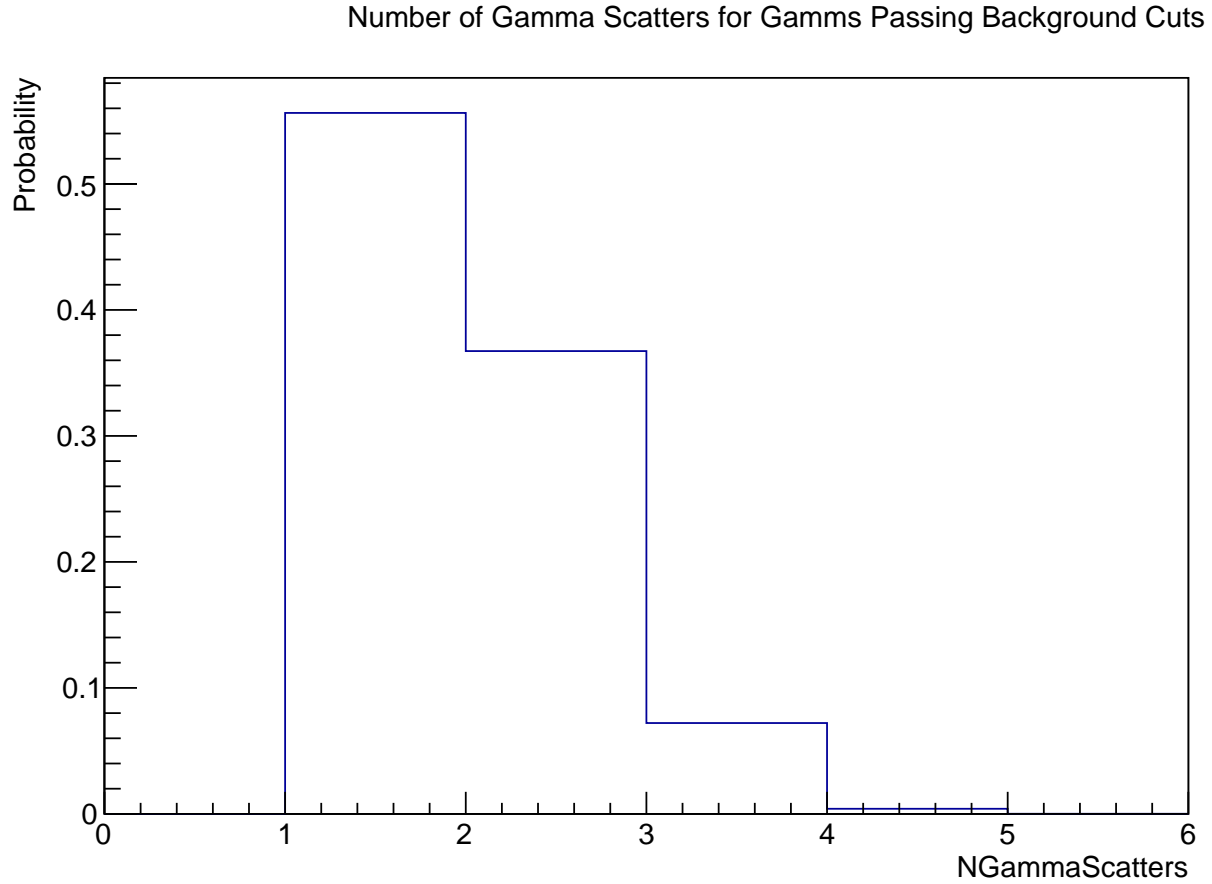Number of Gamma Scatters for Gamms Passing Background Cuts

Figure 1. Number of Gamma Scatters

4. The electron must have greater than 77 keV. This threshold was chosen because it is the threshold for Cherenkov production in liquid xenon. As Cherenkov-based discrimination is one motivation for analyzing the number of gamma interactions, this threshold is appropriate for at least that application. A similar study can be rerun if we are interesting in gamma interactions below this threshold.

Geant4 divides gamma production of recoil electrons into compton scattering (process name "compt"), photoelectric effect ("phot") and conversion electrons ("conv"). I do not use the distinctions between these proceses in this study.

Any fast electron, whether from $0\nu\beta\beta$ or a gamma background, may produce Bremsstrahlung gamma emissions. These gammas will likely go on to produce their own recoil electrons. Bremsstrahlung gammas and their recoil electrons cannot help differentiate between $0\nu\beta\beta$ events and backgrounds, and so any gamma interactions stemming from a Bremsstrahlung gamma are excluded form the count.

IV.   RESULTS

Figure 1 shows the probability an event passing the background cuts has a given number of gamma scatters. The same information is recorded in Table I.

V.   CONCLUSIONS

Cherenkov-based discrimination will necessarily be limited by the 45% of gamma backgrounds that do not produce only a single recoil electron. A background that produces two recoil electrons may be entirely indistinguishable from a $0\nu\beta\beta$ signal even with perfect knowledge of directional behavior by the electrons. After including the challenges of

Gamma Interactions	Probability
1	0.56
2	0.37
3	0.07
4	0.004
5	0.0001

Table I. Number of Gamma Scatters

observing precise directional information using LXe Cherenkopv light, events with > 2 recoil electrons may also be extremely difficult to distinguish from signals.

In a gas TPC, it seems likely there would be significantly fewer SS gamma background with multiple recoil electrons, due to the longer mean free path of gammas. This may enhance a future experiment's ability to perform SS/MS discrimination, but the 0.56% of single-interacting gammas seems irreducible by SS/MS discrimination.

VI. AUSPICES